

Flame Arrester Selection, Standards, and Application

Why propagation phenomena, test protocol, pressure, piping geometry, materials, element design, and maintenance determine actual protection



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Central premise

A flame arrester should not be selected by pipe size, pressure drop, gas group, or the marketing description “detonation arrester” alone. The purchaser must determine what propagation phenomena the certified product has actually been tested to stop, under what pressure, gas, piping, burn, material, and maintenance conditions.

Purchaser’s Initial Operating Pressure (IOP) Check: Section 4. Flow and pressure-drop sizing: Section 9. Optional engineering analysis: Appendix A.

Technical publication for industry education. This paper is not a substitute for the governing regulation, certificate, manufacturer instructions, process hazard analysis, or authority having jurisdiction.



Contents

Application guidance, qualification comparisons and optional calculations. Section numbers are unchanged; page references below apply to this review draft.

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Figure 2 is the original illustrative propagation profile. Appendix A is optional; its calculations do not supersede the applicable product certification.

About the author

Dwight E. Brooker, CET, is an engineering technologist, inventor, and flame-arrester designer with decades of experience in deflagration and detonation flame-arrester development, testing, application, and manufacturing. This paper consolidates historical Paradox technical material with current regulatory references for educational use by engineers, end users, safety professionals, and purchasers.

Abstract

Flame arresters are passive safety devices, but their successful application is not passive engineering. The device must be matched to the combustible mixture, ignition scenario, initial operating pressure, piping geometry, flame acceleration distance, potential for stabilized burning, maximum flow and allowable pressure drop, element geometry, material of construction, environmental conditions, and maintenance program. The governing test standard is equally important because different standards and classification systems do not necessarily qualify a product against the same spectrum of flame-propagation phenomena.

This paper consolidates Paradox IP LLC technical work on flame propagation, U.S. Coast Guard (USCG) detonation-arrester testing, the historical European EN 12874 framework, initial operating pressure (IOP), element design, freezing and fouling, stabilized burning, material behavior, and maintenance. It also incorporates an independent 2004 U.K. Health and Safety Executive (HSE) investigation that documented industry and laboratory concerns that a flame arrester could satisfy BS EN 12874:2001 testing yet still permit flame transmission under some operating conditions. [1-9]

The most important conclusion is that the words on a sales description are not enough. A purchaser who needs broad in-line protection should verify the exact approval or certification, the tested propagation regimes, the gas group or MESH, maximum tested IOP, directionality, burn classification, temperature limits, piping-size limitations, and all installation conditions before assuming that one “detonation flame arrester” provides protection equivalent to another.

Executive Summary

- A flame arrester stops flame by removing heat from a flame front as the reacting mixture passes through narrow heat-conducting channels. Flame-cell geometry and flame-path length are therefore functional safety parameters, not merely manufacturing details. [1]
- The hazard arriving at the arrester can be a low-pressure deflagration, high-pressure deflagration, the deflagration-to-detonation transition (DDT) / unstable or overdriven detonation region, a stable detonation, or a stabilized flame resting on the element. These conditions impose very different pressure, velocity, and thermal loads. [1,2]
- Piping length, L/D, elbows, restrictions, valves, instruments, surface condition, ignition energy, gas composition, temperature, and initial pressure influence flame acceleration. Therefore, predicting that a real system will always deliver only one propagation regime is inherently uncertain. [1]
- The USCG Appendix A test philosophy qualifies a detonation flame arrester across deflagrations, unstable (overdriven) detonations, and stable detonations. The regulation itself defines a detonation flame arrester as a device that prevents transmission of both a detonation and a deflagration. [2]
- The USCG propagation sequence comprises at least 30 events. The historical EN 12874:2001 routes summarized by PTB/BAM comprise six for stable or eight for unstable detonation, with narrower scope. Burning qualification must be compared separately; see Tables 1A–1B. [2,3,34]

- Independent HSE Research Report RR281 (2004) recorded concerns that a flame arrester could satisfy BS EN 12874:2001 yet allow flame transmission under operational conditions, including the “creep flame” problem in which an arrester capable of stopping high-speed events can fail to quench a slower flame. [4]
- EN 12874:2001 is no longer current. It was superseded through EN ISO 16852 and today by EN ISO/IEC 80079-49:2024. The current standard still explicitly distinguishes deflagration, stable detonation, unstable detonation, and stabilized-burning classifications. Consequently, the exact classification on the certificate remains essential; a generic sales description should never replace certificate review. [5]
- Distinguish mechanical pressure capacity, actual operating pressure and the pressure of a credible flame challenge. A supported burn-back crossover assessment can estimate IOP for a particular upstream-flashback scenario; it does not replace the certified operating-pressure limit. Where that limit covers all credible operating states, no crossover calculation is needed. [2,6,33]
- After establishing the required type and ratings, calculate clean-unit pressure drop at the customer’s maximum flow and actual service conditions. Paradox selects well below 30 inches WC, ordinarily around 10 inches WC or lower, meeting any lower customer limit and providing adequate operating allowance for contaminants and fouling before cleaning. Thirty inches WC is an upper sizing cutoff, not an acceptable clean-unit quotation point. A value merely below 30 is not sufficient: evaluate a larger qualified unit when approaching the cutoff; reject candidates at or above it. Greater customer tolerance or blower capacity does not override this practice. [19, Paradox sizing practice]
- No test standard eliminates the need for material and application knowledge. CANMET documented a self-sustaining exothermic reaction in a tested arrester using 316L stainless-steel crimped ribbon after severe heating; the same phenomenon was not reproduced in an otherwise similar 304SS unit. [7]
- Maintenance is part of the safety function. Fouling, corrosion, erosion, ice, condensate, and mechanical damage can change both flow and quenching performance. Inspection should be event-driven as well as time-based. [8,9]

1. Introduction: A Flame Arrester Is a Tested System Component

A flame arrester is commonly described as a device that allows gas or vapor to pass while preventing flame transmission. That description is correct, but incomplete. The arrester does not operate independently of the process system. It is one component in a combustion path that begins at an ignition source and includes the vapor mixture, pressure, temperature, piping length and diameter, bends, restrictions, flow condition, and the arrester itself. [1]

Because the arrester works by absorbing heat from the reacting mixture, the same model can face radically different duty depending on how quickly the flame arrives, the pressure behind it, whether a shock wave has formed, and whether the flame is transient or becomes stationary on the element. Correct selection is therefore a problem in combustion physics, process design, certification, and lifecycle maintenance - not a catalog exercise.

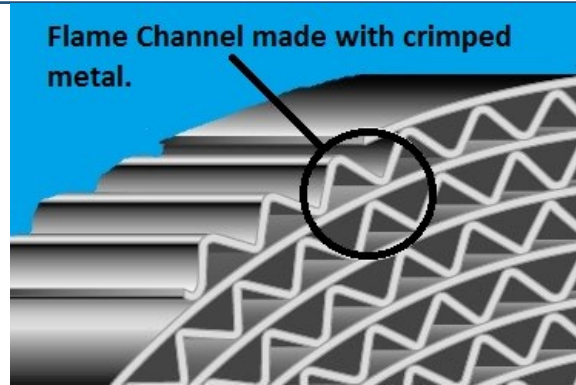


Figure 1. Crimped-ribbon flame channels. Narrow passages provide heat-transfer surface that cools the flame below the temperature required for continued propagation. Source: Paradox flame-arrester technology paper, 2013. [1]

2. Flame Propagation Phenomena

The differences between flame arrester types are driven primarily by flame velocity, pressure rise, and thermal exposure. For selection purposes, the important question is not simply “can the gas burn?” but “what combustion regime can reach the arrester under credible conditions?” [1]

Propagation condition	What it means	Why it matters to selection
Low-pressure deflagration	Subsonic flame propagation with comparatively lower pressure rise.	Typical end-of-line and short-run in-line hazards when ignition is close and acceleration is limited.
High-pressure / accelerated deflagration	Still a deflagration, but with substantial acceleration and pressure rise due to confinement and turbulence.	Can exceed the capability of an arrester qualified only for low-energy deflagration.
DDT / unstable or overdriven detonation	During DDT, transient pressure and flame speed can exceed those of the later stable wave. [23,24]	Require demonstrated unstable-detonation capability; stable-only qualification does not establish protection against this transition challenge. [2,24]
Stable detonation	A developed detonation propagating with a coupled reaction and shock wave.	Stable-only qualification does not demonstrate unstable/overdriven capability. [2]
Stabilized burning	A flame becomes stationary on or near the arrester rather than passing as a short transient.	Creates a thermal-endurance problem; a device that stops a short event may still overheat and transmit flame later.

The description “detonation arrester” alone does not establish equivalent protection. Stable-only qualification does not demonstrate unstable/overdriven capability during deflagration-to-detonation transition. Where that challenge is credible, require demonstrated unstable-detonation protection. Do not assume the event will become stable before reaching the arrester without an adequately supported application assessment. Compare tested detonation coverage, service limits, required approvals and separately demonstrated burning performance before comparing prices. [2,23,24]

2.1 Illustrative propagation profile

Figure 2 shows an illustrative deflagration-to-detonation progression: an accelerating deflagration, a sharp transient overdriven peak, and a lower stable-detonation region. It explains the propagation phenomena, not where they will occur in a particular installation. [23,24,29]

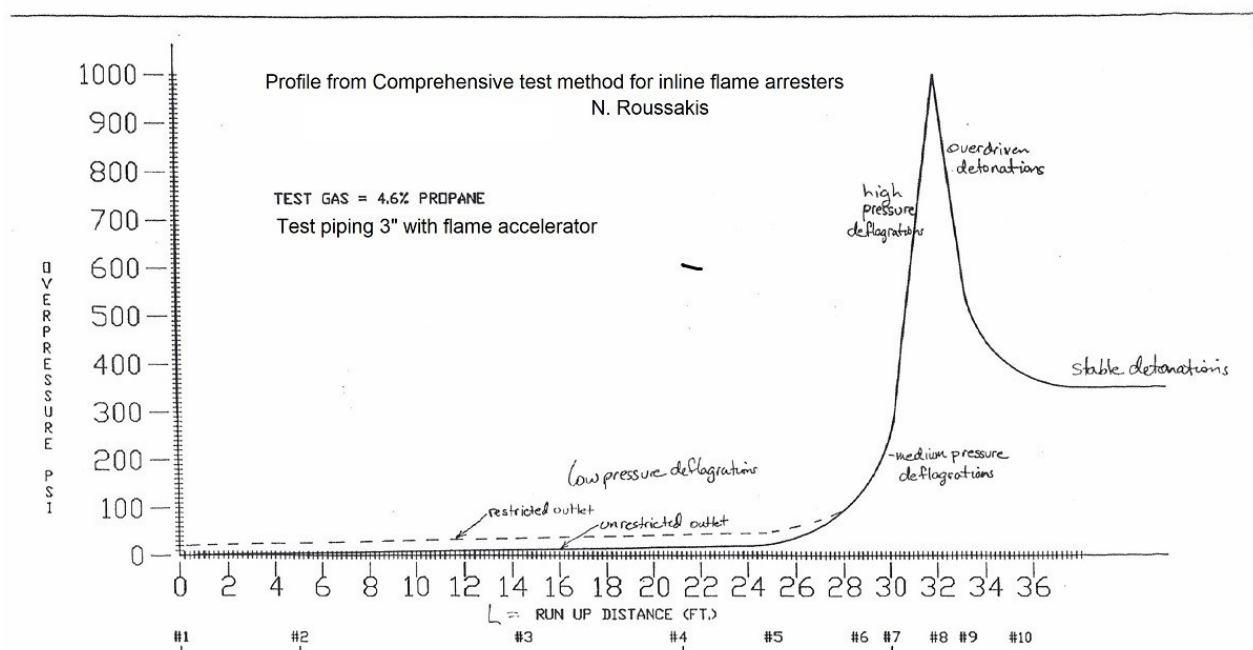


Figure 2. Illustrative laboratory propagation profile, reproduced from the diagram included in Dwight Brooker's "Stable Detonation Arrester & Misleading Marketing" (November 12, 2021). The original credits "Profile from Comprehensive test method for inline flame arresters" to N. Roussakis. Overpressure (psi) is plotted against run-up distance (feet). The plotted distances, pressures, transition position and stable region apply to the illustrated example; they are not universal design values or field placement instructions. [29]

What the profile means for selection

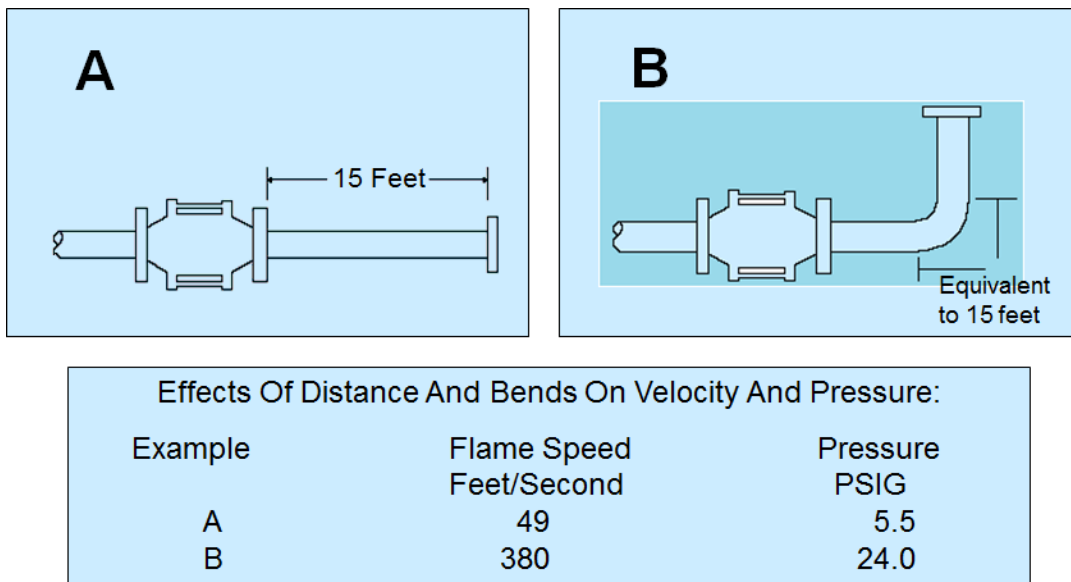
Stable-only qualification does not, on that basis, demonstrate protection against the unstable/overdriven event. Where that challenge is credible, require demonstrated coverage rather than assuming the transition will have ended before reaching the arrester. The profile cannot establish a safe placement distance. [2,23,24]

Stopping flame at one point does not eliminate possible incident-side pressure and thermal exposure of intervening piping and instrumentation. Assess that exposure separately. Burning performance and permitted burn time also remain separate qualifications; this profile does not establish them. [2,23; engineering implication]

3. Piping Geometry, L/D, Turbulence, and Ignition Location

Flame acceleration depends strongly on the distance available for run-up and on the geometry of the system. The 2013 Paradox paper describes the length-to-diameter ratio (L/D) as a practical way to normalize ignition distance for pipe size. It also emphasizes that bends, instrumentation, contractions, expansions, valves, roughness, and other restrictions can increase turbulence and accelerate flame propagation. [1]

This means that the same straight-line distance does not represent the same hazard in every pipe size, and a nominal piping length cannot be evaluated without considering obstructions and fittings. The location of all credible ignition sources is therefore fundamental to the selection of a deflagration arrester and to any attempt to predict whether detonation may develop.



The effects of an elbow on a flame arrester installation

Figure 3. Historical Paradox illustration showing why an elbow or restriction can materially change flame velocity and pressure. The original source expressly identifies the values as an example/visual aid rather than a universal correlation. [1]

Selection implication

If a certificate is limited by maximum run-up distance, L/D, number of bends, or a specific piping configuration, those limits are part of the safety rating. They cannot be treated as installation suggestions.

4. Practical Initial Operating Pressure (IOP) Selection

Initial operating pressure must be considered separately from the mechanical design pressure of the housing. In this paper, the burn-back crossover method estimates the absolute pressure associated with a specified upstream-flashback scenario. A high forward flow can oppose that mechanism; as the local flow declines to an applicable burn-back threshold, upstream flame movement may become possible. This is a conditional application assessment, not a universal definition of the maximum pressure allowed by a certificate. [6,33]

A flare or emergency-depressurization system may start at high pressure. The pressure at the source, the actual pressure at the arrester, and the pressure at a later burn-back crossover must not be assumed identical. Establish the local operating conditions and credible flame challenges, including retained pressure, reverse flow and internal ignition where relevant. Mechanical strength alone does not establish flame-stopping performance. [2,6,33; Appendix A]

4.1 Separate pressure ratings and verify operating temperature

Selection quantity	What it tells the purchaser
Design pressure / MAWP	How much pressure the housing and connections are specified or permitted to contain at the stated temperature. Obtain the actual rating; a flange class alone is not an IP rating.
Actual line pressure	The actual pressure at the arrester during operation and credible startup, shutdown and upset states. Record normal and maximum values separately from the housing rating and any crossover estimate.
Rated initial pressure: IP / IOP	The initial pressure covered by the exact model/configuration's flame-arresting qualification. Also verify its certified maximum operating pressure, gas group, temperature and installation limits. A crossover estimate does not enlarge these limits. [2,6,33]
Operating temperature	The documented service-temperature range for the offered model/configuration. Check the maximum credible gas temperature at the arrester with IOP; identify ambient and heated-device temperatures separately. See the temperature check below. [2,31]

Certified operating limits remain binding

USCG Appendix A, §2.2, conditions application on operation at or below the maximum operating pressure in the manufacturer's certification. Any distinction between a higher permitted flowing pressure and a lower flame-stopping IOP must be expressly supported by the applicable certification, manufacturer instructions and regulatory acceptance where required—not inferred from velocity or housing strength alone. [2; Appendix A.1]

Operating temperature is a qualification limit

Specify the maximum credible process-gas temperature at the arrester, including relevant startup, upset and heating conditions, and the minimum service temperature. Verify the offered model/configuration's documented temperature range together with gas group/composition, initial operating pressure, propagation duty and installation limits. Record ambient temperature and any heated-device surface temperature separately; neither is interchangeable with process-gas temperature. [2,31]

An arrester quenches flame by transferring heat from hot reacting gases to its element. A hotter initial element reduces the temperature difference driving that heat transfer and can reduce quenching margin. This is a qualitative explanation, not a temperature-only acceptance formula: remain within the demonstrated and approved service limits. [1,32; engineering implication]

For service covered by 33 CFR Part 154, Appendix A, §2.1, the maximum vapor-temperature scope is 140°F (60°C). This scope does not establish that every device was physically tested at 140°F or create a universal physical ceiling. Any higher-temperature duty requires applicable documented qualification and approval, not extrapolation of this scope. [2, §2.1; 31]

If requested service exceeds existing documented temperature coverage, do not approve it by extrapolating a standard rating or by a pressure, crossover, flow or pressure-drop calculation. Require applicable elevated-temperature performance testing and documented certification/approval covering the relevant model/configuration and service envelope, or select a configuration already qualified for that duty. Applicable existing qualification need not be repeated; this is not a requirement to fire-test every delivered production unit. [2, §§9.2 and 11.1.1; 31]

Keep process-gas temperature, ambient limits, heated-device surface temperature and burning endurance separate. Appendix A, §9.2.7 requires devices with heating arrangements maintaining a surface above 85°C to pass the required tests at their maximum heated operating temperature; this is not permission to exceed the 60°C process-vapor scope. Heat tracing for freeze protection must follow the approved installation requirements and be controlled to prevent overheating or exceeding applicable temperature limits. Verify the documented ambient range, heating limitations and separate burning qualification. [2, §§5, 9.2.5, 9.2.7, 11.1.1, 11.1.6 and 12.1.9]

Two distinct pressure checks—not interchangeable instructions

For a conservative screening check, a certified operating-pressure limit that covers the supported maximum actual pressure at the arrester avoids relying on a crossover reduction. For a proposed lower flame-challenge pressure, use the conditional assessment in Sections 4.2–4.8 and verify that the complete operating envelope remains permitted by the applicable approval. Neither check substitutes housing design pressure for actual line pressure. [2,6,33]

Example rated IP	Equivalent gauge pressure at 14.7 psia atmosphere
15.4 psia	0.7 psig
15.7 psia	1.0 psig

Example rated IP	Equivalent gauge pressure at 14.7 psia atmosphere
17.7 psia	3.0 psig
19.7 psia	5.0 psig
20.7 psia	6.0 psig
22.7 psia	8.0 psig
24.7 psia	10.0 psig

Pressure conversions only: these examples use a 14.7-psia atmosphere. They are neither operating targets nor proof that products with these ratings are interchangeable. Use site atmospheric pressure and appropriate allowances for a close-limit check; confirm the exact product rating and conditions. [16,17]

4.2 The flashback crossover

For the upstream-flashback scenario being assessed, determine when the local forward gas velocity reaches an applicable burn-back velocity. Use the same location, time, gas composition, pressure and temperature for the flow and pressure data. Flow loss does not necessarily cause pressure loss. The following crossover relationship applies only where the selected flashback criterion and operating history are supported. [6,33; Appendix A.2–A.6]

$$V_{\text{gas}} = V_{\text{burn-back}}$$

$$\text{IOP} = P_{\text{absolute at that crossover}}$$

Here “IOP” is the estimated pressure of this crossover scenario, not an automatic replacement for the rated or permitted operating pressure. Check other credible flame challenges and later low-, zero- or reverse-flow states before determining the required coverage. [2; Appendix A.7]

Emerson/Enardo defines practical burn-back velocity as the superficial average pipe-flow velocity at which an upstream-propagating low-pressure deflagration is stationary, and describes IOP in a flow-decay flashback example. That manufacturer explanation supports the scenario calculation; application must still comply with the actual certificate and acceptance limits. [33, printed pp. 17–18]

4.3 Practical burn-back values: use reference-gas data, not a universal gas-group number

Burn-back velocity depends on composition, mixture ratio, pressure, temperature and the applicable flow/geometry conditions. The published reference values below are not universal gas-group thresholds. Use a numerical value only where its applicability to the assessed service is substantiated; a gas name or MESG group alone is insufficient. [20,33; Appendix A.2–A.3]

Reference gas	Typical group	Published burn-back velocity	Use in this paper
Propane	Group D / IIA	≈ 3.2 m/s (10.5 ft/s)	Practical screening value for propane/air at stoichiometric mixture and standard room conditions.

Reference gas	Typical group	Published burn-back velocity	Use in this paper
Ethylene	Group C / IIB3*	Comparable published burn-back value not verified	Obtain a substantiated, application-specific burn-back value before a numerical crossover check. [33]
Hydrogen	Group B / IIC	≈ 20 m/s (65.6 ft/s)	Practical screening value for hydrogen/air at stoichiometric mixture and standard room conditions.
Other gases / mixtures	Varies	Manufacturer- or process-specific	Do not infer an exact burn-back velocity from MESG or gas-group designation alone.

Table basis: burn-back velocity here means superficial average pipe-flow velocity at which an upstream low-pressure deflagration stands still—not laminar burning velocity. The cited manufacturer gives propane and hydrogen values at stoichiometric mixture and standard room conditions, but no comparable ethylene value. *Ethylene is broadly Group C / IIB; IIB3 is the flame-arrester subgroup used in the manufacturer’s table. Do not substitute a laminar value or derive a burn-back value using an unvalidated multiplier. [33,36] Reference [33] attributes these values to Grossel [21].

API RP 2028 likewise recognizes velocity-type flashback prevention and states that the appropriate velocity must be determined for each case from the gas mixture and pipe diameter. It gives 10 ft/s for gasoline vapor from a small-diameter open pipe as an example rather than a universal rule. These values are therefore screening/application data, not substitutes for the product certificate or manufacturer confirmation. [20]

Do not substitute laminar burning velocity or a nominal burning velocity used in a stabilized-burning qualification method for practical pipe burn-back velocity. Those quantities serve different purposes. A crossover calculation requires an applicable pipe-flashback threshold; the published propane and hydrogen values in this table are specifically described as practical burn-back velocities. [33; Appendix A.2–A.3]

4.4 Convert burn-back velocity to the critical actual flow

Once a burn-back velocity has been selected, convert it to the actual volumetric flow in the pipe. Use the actual internal diameter—not nominal pipe size.

$$A = \pi D^2 / 4 \quad \text{and} \quad Q_{\text{critical,actual}} = V_{\text{burn-back}} \times A$$

Where A is the internal pipe area, D is actual internal diameter, $V_{\text{burn-back}}$ is the selected burn-back velocity, and $Q_{\text{critical,actual}}$ is the actual volumetric flow at the flashback crossover. The result is an actual flow at the local pressure and temperature; it is not automatically SCFM or another standard-volume flow.

4.5 Find the pressure when the system reaches that critical flow

The practical plant question is: during the specified event, at what local absolute pressure does actual flow at the arrester fall to the established critical flow? Use a supported pressure-versus-flow history from operating records or an appropriate process assessment. The crossover estimate does not establish that an ignitable mixture is absent at other pressures or locations. Assess the relevant

gas/air conditions and every credible flame challenge; use the governing pressure with justified uncertainty allowance. [6,33; Appendix A.6–A.7]

For the supported crossover scenario:

$$\text{IOP (psia)} \approx \text{crossover pressure (psig)} + \text{local atmospheric pressure (psi)}$$

Near sea level, 14.7 psi may be used for a screening conversion. Do not add atmospheric pressure to a value already expressed in psia. This is a unit conversion, not a certification or acceptance decision. [16]

4.6 Example: high-pressure emergency shutdown line

Consider a hypothetical 8-inch emergency-depressurization line to a flare, with an initial actual line pressure of 150 psig and high forward velocity. The mechanical design must accommodate the applicable pressure duty. The pressure associated with a later upstream burn-back event must be evaluated separately; high forward velocity alone does not authorize using a device outside its certified operating range. [2,6,33]

For illustration only, assume an applicable burn-back criterion of 3.2 m/s based on the published propane reference, and an actual pipe internal diameter of 7.981 inches (0.2027 m). The area is approximately 0.0323 m², giving a critical actual flow of approximately 0.103 m³/s, or 219 ACFM. This arithmetic does not validate the reference velocity for the hypothetical blowdown. [33]

The plant's depressurization information is then reviewed to find the pressure at which actual flow decays to about 219 ACFM. If that crossover occurs at 5 psig, the approximate IOP is:

$$5 \text{ psig} + 14.7 \text{ psi} \approx 19.7 \text{ psia IOP}$$

A 22.7-psia initial-pressure rating exceeds the hypothetical 19.7-psia crossover estimate numerically, but that comparison alone does not establish suitability for this system. If the arrester actually experiences 150 psig, a certified operating limit of 22.7 psia would not cover that operation. Any distinct higher-flowing-pressure allowance requires explicit support in the applicable approval basis; a 150-psig housing rating is not that support. The crossover pressure is hypothetical, and all relevant events, temperature limits and allowances must be checked. [2, §§2.2 and 4.1; 6,33]

4.7 A purchaser-friendly quotation method

Step	Customer / operator supplies	Manufacturer / selector does
1	Gas or vapor composition / gas group	Select an accepted burn-back velocity basis or request additional composition data.
2	Pipe size and actual internal diameter if known	Calculate pipe area and critical actual flow.
3	Local pressure/flow history for the relevant shutdown/depressurization; normal and maximum actual pressure at the arrester	Estimate the supported crossover; check other credible challenges and the certified operating envelope.
4	Site atmospheric pressure if materially different from 14.7 psia	Convert the crossover estimate to absolute pressure; determine required coverage with justified allowances.



Step	Customer / operator supplies	Manufacturer / selector does
5	Mechanical design pressure/temperature; service-gas temperature range and separate ambient/heated-device temperatures	Verify mechanical rating separately; confirm documented temperature coverage with IOP, gas composition and duty. [2,31]
6	Maximum required flow and maximum allowable ΔP	Size clean unit for maximum flow and operating allowance per Section 9.

The customer supplies the process facts; the manufacturer and responsible plant personnel confirm the applicable assessment and product limits. Where certified limits already cover all credible conditions, a critical-velocity calculation is not a routine purchasing prerequisite. [2,18; Appendix A.7]

Pressure and temperature information for the quotation

“Housing design pressure: ___ psig at ___ °F. Normal and maximum actual pressure at the arrester: ___ / ___ psig; basis: ___. Crossover estimate, if relied upon: ___ psia; applicable scenario and supporting record: ___. Required initial-pressure coverage, including justified allowance: ___ psia. Process-gas temperature range, including startup/upset/heating: ___ / ___ °F (°C). Ambient range: ___. Heated-device surface temperature, if applicable: ___. Confirm that the proposed model/configuration’s documented operating envelope, flame qualification and acceptance cover all these conditions.”

4.8 When the simple crossover method is not enough

Refer the application for detailed review when the applicable burn-back threshold or local pressure/flow history is unsubstantiated, when composition or oxygen content changes, when reverse flow or internal ignition is credible, or when proposed service approaches or exceeds documented limits. A claimed lower crossover pressure must not conceal a higher-pressure challenge. No inferred flow exemption can override the applicable certification or acceptance. [2; Appendix A]

The selected device must remain within its documented operating envelope. Confirm initial-pressure coverage together with gas composition/group, temperature, propagation and burning duty, direction and installation restrictions. A crossover calculation does not enlarge the certified test envelope. [2,25,33]

5. End-of-Line, Deflagration, and Detonation Flame Arresters

End-of-line arresters protect an open vent or termination from external flame entry. In-line deflagration arresters protect piping where a subsonic flame is expected within the tested run-up and configuration limits. Detonation arresters are intended for systems where detonation can develop. Each category exists because the arriving flame and pressure wave are different.

USCG Appendix A defines a detonation flame arrester as preventing transmission of both detonation and deflagration. Its broad in-line test scope remains subject to certified pressure and tested pipe-diameter limits. Where §154.2106 applies, installation must follow the manufacturer's Coast Guard acceptance letter and applicable pipe-expansion restrictions. Neither the test scope nor acceptance authorizes unrestricted placement or guarantees protection of every component in the system. [2,25]



Figure 4. Example of a Paradox USCG-approved in-line detonation flame arrester shown in the author's 2013 technical paper. [1]

6. The Test Standard Is Part of the Product

Two flame arresters can have the same nominal pipe size, gas group, pressure class, and similar pressure drop while representing very different demonstrated safety performance. The test standard and the specific classification achieved under that standard are therefore part of the product specification.

For a purchaser, the important question is whether competing bids cover the same required events. A stable-only detonation offer must not be treated as equivalent to an offer with demonstrated unstable/overdriven capability merely because both are called "detonation arresters." Require the exact model, tested scope and applicable approval before comparing prices. [2; purchasing implication]

6.1 USCG Appendix A: A Spectrum-Based Test Philosophy

USCG Appendix A separately requires stable-detonation, unstable/overdriven-detonation and deflagration challenges. Qualification includes the severe unstable/overdriven challenge at the arrester itself, not only exposure to an already stable wave. The specified sequence includes five stable detonations, at least five unstable challenges, and twenty deflagrations spanning the stated low-/high-pressure and open-/restricted-outlet categories. No flame passage is permitted. [2, §14.3.4]

The protocol tests the transition challenge at the device rather than assuming it happens safely elsewhere. Stable-only qualification does not establish conformity with this Coast Guard detonation-arrester test protocol or substitute for applicable Coast Guard acceptance. The exact accepted model and its service and installation limits must still be checked. [2,25]

6.2 Historical EN 12874:2001 Comparison

Paradox's historical comparison [3] highlights the narrower propagation scope of EN 12874:2001. The public PTB/BAM edition comparison distinguishes its stable route (three stable detonations plus three deflagrations) from its unstable route (five unstable detonations plus three deflagrations). Table 1A therefore distinguishes those routes rather than applying the author's chart total of eight to every EN detonation classification. Burning qualification is a separate selection question, summarized in Table 1B. [2,3,34]

Propagation test	USCG Appendix A	EN 12874:2001 PTB/BAM route comparison
Deflagration - low pressure, open end	5	Three deflagration tests total in either selected route; not the USCG four-category matrix.
Deflagration - low pressure, restricted end	5	
Deflagration - high pressure, open end	5	
Deflagration - high pressure, restricted end	5	
Unstable / overdriven detonation	5 minimum in qualification sequence	5 in the unstable route; not demonstrated by stable-only qualification.
Stable detonation	5	3 in the stable route; unstable route assessed separately.
Minimum propagation events	30; additional unstable-severity runs may be necessary.	6 in the stable route; 8 in the unstable route.

Table 1A. Propagation events only: USCG Appendix A, §14.3.4, compared with the historical EN 12874:2001 routes summarized by PTB/BAM (2010), Table 1. The route-specific EN totals correct the blanket eight-event total in the author's earlier chart. This is not a full qualification-program count or a summary of current European approvals. Burning and specimen continuity follow in Table 1B. [2,3,34]

Burning qualification and tested-specimen continuity

A detonation rating alone may carry no burning qualification. “No burning rating” means that burning protection has not been claimed or demonstrated by that rating; it does not mean the product failed a burn test. Where stabilized burning is credible, the required burning protection and effective shutdown or other protective action must be demonstrated separately. [35, §4.2; 2, §5]

Qualification issue	USCG Appendix A	Historical EN 12874:2001
Burning qualification	Both propagation and endurance-burn testing are required. Type I and Type II have different burning outcomes. [2, §9.2.5]	Separate from detonation classification. Verify no burning rating, short-time or endurance protection. Short-time applies where flow can be stopped within one minute or equivalent effective action is provided; otherwise assess endurance duty. [35, §4.2]
Short-time / Type II (not equivalent classes)	Type II: record maximum temperature, duration and time to flame passage where it occurs. The permitted 15-minute test termination is not guaranteed 15-minute flame resistance. Verify the report and protective action. [2, §§5, 9.2.5, 14.2]	Historical short-time test: one minute, without flame transmission during testing or when flow stops. Integrated sensor: at least 60 K rise within no more than 30 seconds in each test. Check required protective action. [34, Table 2; 35, §6.3.4]
Endurance / Type I (protocols differ)	Type I must show no flame passage in both the propagation and prescribed endurance-burn tests. Apply the actual report and certification; do not infer a universal service duration. [2, §§9.2.5, 14.2]	Endurance qualification continues to thermal stabilization and at least two hours, without flame transmission during testing or when flow stops. Two hours is a minimum test duration, not a service-expiration time. [34, Table 2; 35, §6.3.5]
Specimen continuity	§9.2 specifies testing one of each model/type; both test classes are required. Confirm physical specimen identity, replacement history and sequence in the applicable test/acceptance record. See the source distinction below. [2,3]	One arrester throughout propagation tests without replacing parts or modification. Final short-time/endurance qualification uses the original unmodified explosion-tested element, not a fresh replacement. [35, §§5.8.1, 6.3.4–6.3.5]

Table 1B. Selection-oriented summary; burning classes and protocols are not interchangeable. EN clause details are based on clause findings provided from the author’s standard copy [35]; PTB/BAM independently corroborates the historical burning-duration and sensor distinctions [34].

Specimen-source distinction. The author reports carrying the same physical unit through propagation challenges and then burning in his qualification practice [3]. Appendix A §§9.2 and 9.2.5 establish model testing and both test classes; an explicit no-replacement, all-propagation-before-burning mandate linking the physical specimen across them was not verified from Appendix A alone. Do not confuse the same model with the same specimen. For historical EN, preliminary characterization allowances do not remove the original-element requirement for the final burning qualification. [2,3,35]

Edition distinction. EN 12874:2001’s one-minute short-time test is not EN ISO 16852:2010’s declared burning duration tBT (up to 30 minutes). PTB/BAM lists thermal stabilization and a two-hour minimum endurance test for both editions. These are historical test criteria; confirm the actual offered certificate, allowed duration, sensor and shutdown obligations. Compare bids using Section 6.6, not a detonation label alone. [34, Table 2]

6.3 Independent HSE Concerns About BS EN 12874:2001

The concern was not limited to a manufacturer's opinion. U.K. Health and Safety Executive Research Report RR281, published in 2004, states that concerns had been raised by both industry and testing organizations that a flame arrester tested to BS EN 12874:2001 could satisfy the test process yet permit flame transmission under some operational conditions. The report specifically examined "creep flame," where an arrester that prevents transmission of high-speed deflagrations and detonations can on occasion fail to quench a slower flame. [4]

That finding illustrates an important principle: "more severe" cannot be reduced to a single variable such as flame speed. A slower flame can create a different heat-transfer and residence-time challenge than a fast transient. Certification must therefore be read in terms of the actual phenomena included in the test program.

6.4 Current European / International Standard

EN 12874:2001 has been withdrawn. It was superseded by EN ISO 16852 and, in 2024, by EN ISO/IEC 80079-49:2024 / ISO/IEC 80079-49:2024. The current standard explicitly retains separate flame-transmission classifications for deflagration, stable detonation, unstable detonation, and stabilized burning. [5]

European/ATEX certification is not synonymous with stable-only protection. Published models include different detonation scopes, including stable-and-unstable capability. The relevant distinction is the exact model and its certificate, not the manufacturer's nationality or brand. Check that the offered device covers every required propagation regime and approval; a generic "detonation arrester" description is insufficient. [5,26–28]

Do not buy a label - buy the demonstrated test envelope

A stable-only bid is not a like-for-like alternative when unstable/overdriven protection is required. A detonation rating may also have no burning rating. Compare actual propagation coverage, no/short-time/endurance burning qualification, required approval, gas group/MESG, IOP, temperature and installation limits before price. See Sections 6.2 and 6.6.

6.5 The transition cannot be assumed to occur at a safe distance

In the DDT mechanism considered here, the transient overdriven event can be more severe than the later stable wave. Its location varies with mixture, initial conditions and piping. Under some conditions, galloping behavior can involve repeated weakening and renewed transition; the event is not guaranteed to make one irreversible change into a permanently stable wave. Unsupported placement assumptions leave a protection gap with potential flame transmission, structural damage and serious consequences. [23,24]

Historical HSE Research Report 281 describes overdriven detonation as transient and notes that transition location varies with the arrester, ignition source and initial temperature, pressure and concentration. It also reports effects of quenching elements on transition behavior. These findings concern BS EN 12874:2001 and support caution about assumed placement; they are not findings that every current certification or model fails. [4, §5.3, pp. 17–18; §6.6, p. 27]

Stopping flame at the arrester does not remove the incident pressure and thermal exposure of piping, instruments and other equipment between the ignition source and the arrester. Those components may be damaged even when flame transmission is stopped. Evaluate ignition-side exposure separately as part of system protection; successful arrest does not guarantee that intervening equipment survives. [2,23; engineering implication]

6.6 Non-equivalent bids: compare protection before price

The author reports non-marine competitive bids in which lower-priced PROTEGO stable-only models, rather than that manufacturer's Coast Guard model, were compared with his own broader-duty offerings. Some customers he spoke with did not realize that the offered detonation coverage differed. This is the author's reported bid and customer experience, not independently established market-wide pricing data or evidence of deliberate misrepresentation. [30]

The published product descriptions below illustrate why the model offered matters. They do not identify the models in any particular past bid, establish a price relationship, or replace review of the actual certificate and acceptance letter.

Illustrative model	Published detonation coverage	Approval basis to verify
PROTEGO DR/SBW	Deflagrations and stable detonations; the cited page does not claim unstable-detonation capability. [26]	Manufacturer describes ATEX type approval. Obtain the exact certificate and limits.
PROTEGO DA-CG	Deflagrations plus stable and unstable detonations. [27]	Manufacturer states approval under 33 CFR Part 154 and USCG acceptance. Verify the model/size acceptance letter.
PROTEGO DA-UB	Deflagrations plus stable and unstable detonations. [28]	Manufacturer states ATEX conformity. That statement alone does not establish Coast Guard acceptance.

Table 2. Manufacturer-published scope examples, checked September 16, 2026. This is not an independent certificate audit or a comparison of price, weight or burning time. [26–28]

Compare demonstrated protection before comparing price. A detonation arrester label alone does not establish equivalent performance. Confirm whether each offered model covers stable and unstable detonations, whether it has no burning rating, short-time burning protection or endurance-burning protection, and what operating limits and shutdown requirements apply. A lower-priced product is not an equivalent substitute if it lacks protection required by the application. Price alone does not establish suitability. [2,34,35; purchasing implication]

Compare each bid	Required evidence before price comparison
Propagation coverage	Document deflagration, stable-detonation and unstable/overdriven coverage for the exact offered model.
Burning protection	State none / short-time / endurance. Record applicable duration, temperature-sensor obligations and required shutdown/protective action; Type I/II are not direct EN class equivalents.
Gas and operating limits	Confirm gas group/MESG and composition, maximum initial operating pressure and qualified temperature range.
Installation and approval	Confirm direction, pipe-size/transition and placement restrictions, and the exact approval required for the service.

Only offers meeting the application's required protection proceed to price comparison. A detonation rating without burning qualification cannot satisfy a specified burning-protection requirement; a higher price does not prove suitability either. See Section 6.2 for the historical burning and specimen distinctions. [2,34,35; purchasing rule]

7. Stabilized Burning and Type I / Type II Protection

Stopping a transient flame is different from surviving a flame that stabilizes on the element. Under stabilized burning, continuous heat input can raise the element temperature until its quenching margin is reduced, the material deforms or reacts, or flame eventually transmits. This is why burn classification and shutdown philosophy must be treated separately from detonation classification.

USCG Appendix A classifies Type I detonation flame arresters for applications where stationary flames may rest on the device. Type II devices are intended for applications where stationary flames are unlikely to rest on the device and where another method is provided to prevent flame passage if a stationary flame occurs; the regulation gives a temperature monitor and automatic shutoff valve as an example. [2]

Burning resistance and permitted burn time require separate demonstration; neither follows from a detonation label or product weight. Record whether the offered configuration has no burning rating, short-time protection or endurance protection, and verify its actual duration, sensor and shutdown requirements. USCG Type I/II provisions and the historical EN classes have different criteria; see Table 1B. Type II's 15-minute test-termination provision must not be quoted as guaranteed 15-minute resistance. [2, §§5, 9.2.5 and 14.2; 34,35]

8. Materials of Construction: Approval Does Not Eliminate Material-Specific Hazards

Material selection affects corrosion resistance, mechanical strength, thermal response, and in some cases chemical behavior at high temperature. The USCG standard recognizes this by treating a design, material, or construction change that may affect corrosion resistance, endurance burning, deflagration resistance, or detonation resistance as a change of model for testing purposes. [2]

A particularly important historical case is documented in the cited 316L stainless-steel report and its 1992 CANMET correspondence. During testing of a 3-inch flame arrester, CANMET observed a self-sustaining exothermic reaction after the element core was heated sufficiently. Once initiated, the reaction continued with airflow even after combustible fuel was removed, causing extensive destruction of the element. CANMET reported that the phenomenon had not been observed in other arresters it had tested and expressed concern about field stabilized-burn conditions. [7]

Paradox later reported that the phenomenon was not reproduced in an otherwise similar unit using 304 stainless steel. The definitive chemical mechanism was not established in the source documentation. Accordingly, the correct engineering conclusion is not to generalize beyond the evidence, but to recognize that material substitution in a flame element is a safety-critical design change and should not be accepted solely because the substitute alloy is conventionally considered “more corrosion resistant.” [7]

Standards are necessary, but not sufficient

The 316L case is a useful counterbalance to any claim that approval alone guarantees safety in every service. A comprehensive test protocol is essential, but material behavior, process chemistry, maintenance, and abnormal operating conditions must still be evaluated.

9. Practical Flow Sizing, Pressure Drop, and Element Condition

9.1 Start with two flow-sizing questions

Once the appropriate arrester type, gas group, required IP, burn classification, and installation limits have been established, calculate the clean arrester’s pressure drop at the customer’s maximum required gas or vapor flow and actual service conditions. Select for both the required flow and adequate operating allowance, not merely for a matching connection size. The following procedure records Paradox’s stated quotation practice. [19, Paradox sizing practice]

Ask the customer: “What is the maximum required flow rate?” and “What is the maximum pressure drop permitted across the flame arrester at that maximum flow rate?” These are two separate quotation entries. [18,19]

Record the flow units and reference conditions. For example, distinguish standard cubic feet per minute (SCFM) from actual cubic feet per minute (ACFM). Supply the gas or vapor composition, operating temperature, and operating pressure so the manufacturer can use the appropriate flow-capacity data. The reference-state distinction is explained in Appendix A. [18; Appendix A.4]

9.2 Select well below the upper sizing cutoff

Paradox selects the clean arrester for the customer’s maximum required flow and actual service conditions at a pressure drop well below 30 inches WC, ordinarily around 10 inches WC or lower. Meet the customer’s lower limit and applicable service needs; some customer specifications are as low as 1 inch WC. Provide adequate operating allowance for increased restriction from

contaminants and fouling before cleaning is required. Starting too close to the cutoff leaves too little useful operating allowance. [19, Paradox sizing practice]

30 inches WC is an upper sizing cutoff—not a target or acceptable clean new-unit quotation point.

A value merely below 30 inches WC is not automatically acceptable. A customer's ability to tolerate greater pressure drop, including available blower capacity, does not override Paradox's restriction. Reject a candidate at or above the cutoff. If a candidate approaches the cutoff, evaluate the next larger qualified unit and recalculate until the selection meets the customer's limit and provides adequate operating allowance from the outset. [19, Paradox sizing practice]

This is internal Paradox sizing policy, not a universal code limit. It does not establish 30 inches WC as a validated safe in-service limit or cleaning threshold. No fixed numerical fouling allowance or cleaning interval is prescribed here; inspection and cleaning requirements must suit the actual service and the manufacturer's instructions. [8; 19, Paradox sizing practice]

Confirm whether the customer's limit applies to the arrester alone or to the entire installed assembly. If it is a total-system allowance, the plant must identify the portion available for the arrester after other line and equipment losses. Do not assign the full system allowance to each component separately. [18; Appendix A.5]

9.3 Select a larger qualified size when necessary

Use the manufacturer's applicable flow-capacity data to calculate clean-unit pressure drop at maximum required flow and actual service conditions. Evaluate the next larger qualified unit whenever the candidate approaches the cutoff, fails the customer's lower limit, or lacks adequate operating allowance; reject it at or above 30 inches WC. Recalculate after each change. The quotation should state the maximum flow, service conditions, selected qualified size, predicted clean pressure drop at that flow, and the basis for the operating allowance. [19, Paradox sizing practice]

Hypothetical example: the customer requires 1,000 SCFM (reference conditions: 60 °F and 14.7 psia) with no more than 10 inches WC across the arrester. Assume the manufacturer's calculation at the actual service conditions gives 18 inches WC for one clean candidate and 7 inches WC for a larger clean candidate at the same duty. The first fails the customer's limit. The larger candidate meets that numerical limit, but selection still requires confirmation of adequate service-specific operating allowance and an approved installation. These illustrative values are not product flow data, a fixed fouling allowance, or approval of an installation.

Existing or predesigned pipe size cannot force selection of an undersized arrester; no suitable unit in that nominal size may meet the duty. A larger qualified arrester with a step-up transition from the smaller line may be required, subject to that model's approved or certified installation. Do not reduce a larger line through a smaller unsuitable arrester merely to make it fit. Increased approved element area may be available independently of flange size; select by the qualified configuration and its flow performance, not flange size alone. [9; 19, Paradox sizing practice]

Before specifying a transition, verify the selected model/type's certificate and installation instructions for pipe-diameter limits, protected- and unprotected-side arrangements, transition

locations, and required straight lengths. Obtain manufacturer confirmation where the proposed arrangement is not expressly covered; this paper does not approve every transition. Preserve the required gas group, propagation protection, IP and burn ratings. Do not enlarge flame-cell gaps or substitute a less protective element to reduce pressure drop. [2,9,22]

9.4 Keep pressure drop separate from IP

Pressure drop describes resistance to flow. IP describes the absolute initial pressure covered by flame-arresting qualification, while housing design pressure describes mechanical pressure containment. Passing the hydraulic sizing check does not replace either pressure-rating check. The same pressure drop can occur at different absolute line pressures. [2,6,18]

For simultaneous inlet and outlet readings in the same pressure units, $\Delta P = P(\text{inlet}) - P(\text{outlet})$. Thirty inches of water column is approximately 1.084 psi of pressure difference—not a 30-psia initial-pressure rating. Downstream pressure and other operating states still matter when establishing the IP requirement in Section 4. [16; engineering distinction]

9.5 Preserve element geometry and allow for condition changes

Flame quenching is produced by a combination of flame-path length, heat-transfer surface, material properties, and hydraulic diameter of the channels. A design using a very short flame path generally requires smaller channels to provide adequate quenching. Smaller channels can increase pressure drop and can be more sensitive to ice, condensate, corrosion products, or particulate blockage. [9]

The June 2026 Paradox evaluation of methanol scrubber vents recommends increased approved total element area to reduce face velocity and pressure drop, while retaining tested flame-cell dimensions. It also discusses longer flame paths and larger hydraulic diameters within qualified designs, drainage and installation orientation, weather protection, heat tracing, insulation, differential-pressure monitoring, and inspection/cleaning. Increasing total element area is not permission to enlarge flame-cell gaps beyond the tested and approved design. [9, Sections 4–6] Apply the heat-tracing temperature precautions stated with the selection definitions.

For that near-atmospheric wet methanol-scrubber vent, the identified concern is ordinary icing rather than gas hydrate formation. Paradox’s conservative sizing practice also considers freezing and, where applicable to other service, hydrate concerns; the relevant composition, pressure and temperature must be assessed separately. Low pressure drop alone does not prevent icing or establish freedom from hydrates, and no passive device guarantees that ice will never form. Appropriate freeze protection and maintenance remain necessary. [9, Sections 2 and 7; 19, Paradox sizing practice]

This principle applies beyond freezing. Any deposit that reduces open area increases pressure drop and changes flow distribution. Corrosion or erosion that enlarges channels can reduce heat transfer and allow flame passage. Both “too closed” and “too open” can be unsafe, for different reasons.

10. Inspection and Maintenance Are Part of the Safety Function

A flame arrester is frequently installed and then ignored because it has no moving parts. That is a dangerous interpretation of “passive.” The safety function depends on the continued integrity and cleanliness of the flame channels.

Paradox maintenance guidance instructs users to inspect for corrosion, erosion, mechanical damage, and blockage; clean the element with suitable media; avoid rodding or hard objects that can deform the cells; and replace an element that cannot be satisfactorily cleaned. It also calls for immediate inspection after a suspected deflagration, detonation, or stabilized-burn event. [8]



Figure 5. Historical photograph of a severely degraded flame-arrester element from the author's earlier field investigation material. It illustrates why condition of the element is part of the safety function. [1,8]

Inspection intervals should be based on service severity and actual fouling rate, not only on a calendar. Differential pressure can be a useful condition indicator but does not detect every failure mode. Visual inspection and dimensional verification of flame cells should follow the manufacturer's approved criteria. The pin-gauge dimensions published in Paradox's cleaning bulletin are product- and gas-group-specific examples, not universal dimensions for all manufacturers. [8]

11. Minimum Information Required Before Selecting or Quoting a Flame Arrester

The following information should be established before a flame arrester is selected. If one of these items is unknown, the uncertainty should be resolved rather than hidden by a generic product description.

Selection input	Required application information
Combustible mixture	All gases/vapors, concentrations if known, MESG / equipment group, possible reaction or decomposition products.
Protection objective	End-of-line external flame entry, in-line deflagration, detonation, or combined protection.
Ignition sources	Location, credible energy level, burner/flare, electrical, static, hot work, rotating equipment, external fire.
Piping geometry	Diameter, total run-up length, L/D, elbows, tees, valves, reducers, restrictions, instruments, roughness.
IOP	Required initial-pressure coverage in psia and its basis. If relying on a crossover, document the supported scenario, other credible challenges and allowances. Separately verify the complete operating envelope against the certificate/acceptance; do not substitute housing pressure. [2,6,33; Section 4]
Normal/design pressure	Normal and maximum actual line pressure, plus the separate housing design pressure/MAWP, temperature and flange class.
Temperature	Minimum/maximum gas temperature at the arrester, including startup/upset/heating; separate ambient range and heated-device temperature. Confirm model/configuration temperature coverage with gas group, IOP and duty; obtain applicable elevated-temperature qualification for uncovered service. Burning endurance is separate. [2,31]
Burn potential	Can flame stabilize? State required and offered burning qualification: none, short-time or endurance; identify USCG Type I/II where applicable. Verify actual duration, temperature sensing and shutdown/protective-action obligations. No burn rating is not a failed test. See Table 1B. [2,34,35]
Flow / pressure drop	Maximum flow with units/reference conditions; actual service conditions; customer's maximum ΔP at that flow and whether it covers the arrester alone or the installed assembly. Manufacturer to confirm clean ΔP well below 30 inches WC, ordinarily around 10 or lower, meeting the customer's lower limit with adequate operating allowance. Reject candidates at or above 30; assess a larger qualified unit when approaching it. [19, Paradox sizing practice]
Materials	Housing, element, gaskets, corrosion, chemical compatibility, high-temperature behavior.
Environment	Condensation, freezing, rain/snow, salt, dust, polymerization, particulate or mist carryover.
Certification	Exact model, standard and certificate/acceptance letter: demonstrated deflagration, stable and unstable coverage; no/short-time/endurance burning qualification; gas group/MESG and composition, IOP, temperature and installation limits. Resolve missing required capability before price comparison. See Section 6.6. [2,25,34,35]
Maintenance	Inspection access, cleaning method, differential-pressure monitoring, event inspection, dimensional verification, spare element plan.

12. Common Specification Errors

1. Specifying only “detonation flame arrester” without naming the standard and exact detonation classification.
2. Treating a stable-only detonation bid as equivalent to one qualified for unstable/overdriven duty, or assuming the transition will occur at a safe distance and settle before reaching the arrester.
3. Confusing housing design pressure, actual line pressure, a scenario-specific crossover estimate and certified pressure limits; or assuming forward flow permits operation outside the approved envelope.
4. Ignoring piping geometry and distance from credible ignition sources.
5. Selecting by connection size alone, checking pressure drop only at average flow, quoting a clean unit near the 30-inch cutoff without adequate operating allowance, accepting a unit at or above it because of customer tolerance or blower capacity, ignoring a lower customer limit, or enlarging flame-cell gaps to reduce restriction.
6. Changing element material for corrosion resistance without determining whether the change is within the approved model and burn performance.
7. Assuming a detonation rating includes burning protection, or treating no burning rating as a failed burn test rather than an absence of claimed/demonstrated burning qualification.
8. Failing to provide automatic shutdown where the selected burn classification requires it.
9. Treating a passive flame arrester as maintenance-free.
10. Assuming a certificate title or sales brochure provides the same information as the actual approval report and limits of use.

13. Selecting the Standard Is a Safety Decision

The standard chosen for a flame arrester determines what has been demonstrated. It defines the test mixture, pressure, piping arrangement, number and type of shots, burn testing, instrumentation, pass/fail criteria, marking, and limits of use. Two approvals that both contain the word “detonation” can therefore represent different demonstrated test envelopes.

For applications where the exact propagation regime cannot be predicted with high confidence, a standard that tests across the propagation spectrum reduces reliance on prediction. USCG Appendix A is notable in this respect because it explicitly defines a detonation flame arrester as stopping both deflagration and detonation and requires qualification across low- and high-pressure deflagrations, restricted and open downstream conditions, unstable/overdriven detonations, and stable detonations. [2]

The historical EN 12874:2001 comparison illustrates the opposite risk: a classification-based system can allow a product to be legitimately described within a detonation category while not having been tested against the other detonation regime in the same way as a USCG-approved device. Independent HSE work from that period also documented real concerns about flame transmission outside the expected high-speed regime. [3,4]

Modern EN ISO/IEC 80079-49:2024 is not EN 12874:2001, and it should be evaluated on its own current requirements. However, it continues to distinguish the different propagation classifications.

The enduring lesson is therefore unchanged: the buyer must specify and verify the exact classification and limits rather than rely on the generic word “detonation.” [5]

14. Conclusions

Flame arresters are deceptively simple devices applied to a complex combustion problem. The narrow channels that quench flame are only the final barrier in a system whose behavior is determined by mixture, ignition, pressure, flow, piping, turbulence, and time.

1. The flame-propagation regime expected at the arrester must be identified, but uncertainty in that prediction must also be recognized.
2. The governing test standard and exact certification classification are fundamental selection criteria.
3. Stable-only qualification does not demonstrate unstable/overdriven protection or Coast Guard protocol conformity. Compare required propagation coverage, no/short-time/endurance burning qualification, approvals and service limits before price; assess ignition-side exposure. [2,23–25,34,35]
4. Keep mechanical rating, actual operating pressure and scenario-specific IOP separate. Use the supported crossover method only within its stated conditions; evaluate other credible challenges and comply with the certified operating envelope. A higher-pressure flow assumption cannot override the applicable acceptance. [2,6,33]
5. Stabilized burning is a separate thermal hazard and can require endurance-burn qualification, temperature detection, and automatic shutdown.
6. Size the clean arrester at maximum required flow and actual service conditions well below 30 inches WC, ordinarily around 10 or lower, meeting the customer’s lower limit with adequate operating allowance. Reject candidates at or above the cutoff and assess larger qualified units when approaching it. Customer tolerance or blower capacity cannot override this Paradox practice. Preserve approved element geometry, ratings, and transition restrictions. [19, Paradox sizing practice]
7. Materials of construction can introduce hazards not obvious from conventional corrosion tables; material substitutions require engineering and certification review.
8. Fouling, corrosion, erosion, freezing, and mechanical damage can defeat the flame-arresting function, so inspection and maintenance are part of the safety system.
9. The certificate, test report, manufacturer instructions, and actual installation conditions should be reviewed together before the device is accepted for service.

Final selection principle

The correct question is not “Is this a detonation flame arrester?” The correct question is “Exactly what propagation phenomena, gas group, initial pressure, burn condition, direction, temperature, pipe size, and installation limits has this specific device been demonstrated to stop?”

References

- [1] Brooker, Dwight. “Flame Arrester Technology, Application, Construction & Standards.” Paradox Intellectual Properties Inc., 2013. Author-provided technical paper.
- [2] Electronic Code of Federal Regulations. 33 CFR Part 154, Appendix A, “Guidelines for Detonation Flame Arresters.” §§2.1–2.2, 4.1, 5, 6, 9.2, 11–12 and 14. <https://www.ecfr.gov/current/title-33/chapter-I/subchapter-O/part-154/appendix-Appendix%20A%20to%20Part%20154> (accessed September 17, 2026).
- [3] Paradox. “USCG VS EN Test Protocol.” Author-provided historical comparison. Historical test-count and specimen assertions are qualified by the primary-source distinctions in Tables 1A–1B.
- [4] Oakley, G. L.; Thomas, G. O. “Investigations into concerns about BS EN 12874:2001 flame arresters—Performance requirements, test methods and limits for use.” HSE Research Report 281, 2004. §§5.3 and 6.6, printed pp. 17–18 and 27. Public copy of the HSE report: https://paradoxintellectual.com/uploads/3/5/0/4/35044814/rr281_investigation_into_concerns_en12874.pdf (accessed September 17, 2026).
- [5] ISO/IEC 80079-49:2024 / EN ISO/IEC 80079-49:2024. “Explosive atmospheres—Part 49: Flame arresters—Performance requirements, test methods and limits for use.” First edition, 2024. Current successor to ISO 16852 / EN ISO 16852. ISO catalogue: <https://www.iso.org/standard/83357.html> (accessed September 17, 2026). Historical comparisons in this paper do not substitute for the applicable current certificate.
- [6] Brooker, Dwight. “Flame Arrester Selection Criteria: Initial Operating Pressure (IOP) vs. Normal Operating Pressure.” Paradox IP LLC, revised May 1, 2026. Author-provided technical guidance. The pressure-duty distinction is applied subject to the qualifications in Section 4 and Appendix A.
- [7] Brooker, Dwight. “Safety Hazards Associated with 316L Stainless Steel in Flame Arresters and Anti-Flashback Burners,” with CANMET correspondence dated June 5, 1992. Paradox IP LLC technical report, 2025; author-provided exhibits.
- [8] Paradox. “Flame Arrester Maintenance & Cleaning Bulletin.” Copyright 2019/2023. Author-provided product guidance; inspection criteria are model-specific.
- [9] Brooker, Dwight E. “Technical Evaluation of End-of-Line Flame Arresters for Methanol Scrubber Vent Service Under Freezing Conditions.” Paradox IP LLC, June 2026. Author-provided technical evaluation; scoped to the described service.
- [10] Jo, S. “Flashback in diluted hydrogen flames.” International Journal of Hydrogen Energy 126 (2025), 159–169. <https://doi.org/10.1016/j.ijhydene.2025.04.029>. Critical-gradient and flashback distinctions; not a source of universal process-pipe velocities.
- [11] Vance, F. H.; de Goey, L. P. H.; van Oijen, J. A. “Development of a flashback correlation for burner-stabilized hydrogen-air premixed flames.” Combustion and Flame 243 (2022), 112045. <https://doi.org/10.1016/j.combustflame.2022.112045>. Model limitations and heat-transfer/flame-structure effects.
- [12] NASA Glenn Research Center. “Mass Flow Rate.” Beginner’s Guide to Aeronautics. <https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/mass-flow-rate/> (accessed September 14, 2026).
- [13] NASA Glenn Research Center. “Equation of State.” Beginner’s Guide to Aeronautics. <https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/equation-of-state/> (accessed September 14, 2026). The Z correction and reference-flow conversion in Appendix A are explicitly stated engineering extensions.

- [14] ASHRAE. 2025 ASHRAE Handbook—Fundamentals, Chapter 3, “Fluid Flow,” sections on generalized Bernoulli analysis and conduit friction. https://handbook.ashrae.org/Handbooks/F25/IP/f25_ch03/f25_ch03_ip.aspx (accessed September 14, 2026). Equation (A-6) is presented in coherent SI units.
- [15] NASA Glenn Research Center. “Bernoulli’s Equation.” Beginner’s Guide to Aeronautics. <https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/bernoullis-equation/> (accessed September 14, 2026).
- [16] NIST. “Pressure and Gas Flow Unit Conversions.” Standard atmosphere = 14.6959 psi; 1 psi = 27.67990 inches of water. <https://www.nist.gov/pml/owm/metric-si/unit-conversion/pressure-and-gas-flow-unit-conversions> (accessed September 14, 2026).
- [17] Protectoseal. “Bi-Directional Detonation Flame Arresters, Series 35000 / 36000RP.” Published IP ranges and USCG size information, not an independent approval audit. <https://www.protectoseal.com/product/vapor-and-flame-solutions/flame-detonation-arresters/in-line-detonation-flame-arresters/series35000-36000rp/> (accessed September 14, 2026).
- [18] Protectoseal. “Detonation Arrester Application Worksheet,” V-DA (01/08). Separate design-pressure, operating/maximum-pressure and pressure-drop fields. https://protectoseal.com/PDF_VENTS/MISCELLANEOUS/DetonationArresterWorksheet.pdf (accessed September 14, 2026).
- [19] Brooker, Dwight E. Paradox IP LLC quotation and hydraulic-sizing practice, September 2026. Author-stated company policy: select clean-unit pressure drop at maximum required flow well below the 30-inch-WC cutoff, ordinarily around 10 inches WC or lower, meeting customer limits with adequate operating allowance. This policy is not a universal code limit or a validated in-service cleaning threshold.
- [20] American Petroleum Institute. API Recommended Practice 2028, “Flame Arresters in Piping Systems,” 3rd edition, February 2002. Historical velocity-type flashback-prevention discussion; the gasoline-discharge example is application-specific, not a universal design value.
- [21] Grossel, Stanley S. Deflagration and Detonation Flame Arresters. AIChE/CCPS, 2002. ISBN 978-0-8169-0791-5. <https://doi.org/10.1002/9780470935651>. The reference burn-back values used here are cited through Emerson/Enardo [33], not independently extracted from this book.
- [22] Emerson / Enardo. EN-7 Series Flame Arrestor Instruction Manual, D103583X012, March 2026, pp. 9–10, “Piping Expansions and Reductions Adjacent to Flame Arrestors.” Model-specific restrictions, not installation rules for every Paradox product. <https://www.emerson.com/content/dam/emerson/en/final-control-fctl/pressure-management/documents/enardo-en-7-series-flame-arrestor-north-america-manual-d103583x012.pdf> (accessed September 17, 2026).
- [23] AIChE/CCPS. “Overdriven Detonation,” Process Safety Glossary. DDT-specific definition and severe arrester test challenge. <https://www.aiche.org/ccps/resources/glossary/process-safety-glossary/overdriven-detonation> (accessed September 16, 2026).
- [24] Cahill, Jim. “Detonation Arrestors for Unstable Detonation Conditions in Piping Systems.” Emerson Automation Experts, May 26, 2015. Manufacturer engineering discussion of DDT location, stable-only limitations and galloping behavior. <https://www.emersonautomationexperts.com/2015/valves-actuators-regulators/detonation-arrestors-for-unstable-detonation-conditions-in-piping-systems/> (accessed September 16, 2026).
- [25] Electronic Code of Federal Regulations. 33 CFR §154.2106(a)–(b), “Detonation arresters installation.” Acceptance-letter and pipe-expansion requirements within that section’s scope. [https://www.ecfr.gov/current/title-33/chapter-I/subchapter-O/part-154#p-154.2106\(a\)](https://www.ecfr.gov/current/title-33/chapter-I/subchapter-O/part-154#p-154.2106(a)) (accessed September 17, 2026).
- [26] PROTEGO. “DR/SBW,” manufacturer product description: deflagration and stable-detonation scope. <https://www.protego.com/products/product-search/dr-sbw> (accessed September 16, 2026).
- [27] PROTEGO. “DA-CG,” manufacturer product description: deflagration, stable and unstable detonation, and stated Coast Guard acceptance. <https://www.protego.com/products/product-search/da-cg/> (accessed September 16, 2026).

- [28] PROTEGO. “DA-UB,” manufacturer product description: deflagration, stable and unstable detonation, with stated ATEX conformity. <https://www.protego.com/products/product-search/da-ub/> (accessed September 16, 2026).
- [29] Brooker, Dwight. “Stable Detonation Arrester & Misleading Marketing,” November 12, 2021. Author-provided article in “Profile showing typical propagation phenomenon in a piping system.docx.” Figure 2 reproduces its original illustrative profile, credited within the image to N. Roussakis. The profile is not a universal design curve or field-placement instruction.
- [30] Brooker, Dwight E. Author’s account of non-marine competitive bids and customer discussions, September 2026. Anecdotal application experience, not independently audited market data.
- [31] PROTEGO. “DR/ES,” manufacturer product description, “Function and Description” and operating-temperature specification. Standard design up to 60°C/140°F; special approvals for higher temperature are described. Used to establish that extended qualifications exist, not to select a model for an unspecified service. <https://www.protego.com/products/product-search/dr-es/> (accessed September 16, 2026).
- [32] PROTEGO. “Flame Arresters,” “Working principle of Flame Arresters.” Heat transfer from the reacting mixture to the flame-quenching surfaces. The thermal-margin discussion in the temperature check is an engineering implication, not a temperature-only acceptance equation. <https://www.protego.com/products/flame-arresters/> (accessed September 16, 2026).
- [33] Emerson / Enardo. “Flame Arrestor Technology.” Printed pp. 17–18: practical burn-back definition, propane/hydrogen reference values and IOP discussion; p. 20, Table 1: ethylene Group C / IIB3; p. 24: gas-group listings. No directly comparable ethylene burn-back value is supplied in that discussion. <https://www.emerson.com/content/dam/emerson/de/final-control/pressure-management/flame-arrestors/Flame%20Arrestor%20Technology.pdf> (accessed September 17, 2026).
- [34] PTB/BAM. “EC type-examination certificates of static flame arresters with crimped ribbon flame arrester elements,” July 2010. Table 1, p. 3: EN 12874:2001 versus EN ISO 16852:2010 propagation routes; Table 2, p. 4: burning-duration and sensor criteria. Used as a historical comparison, not a summary of all current approvals. https://www.ptb.de/cms/fileadmin/internet/fachabteilungen/abteilung_3/explosionsschutz/merkblaetter/nicht_elektrisch/EC_Type_Certificates_09_2010.pdf (checked September 16, 2026).
- [35] EN 12874:2001. “Flame arresters—Performance requirements, test methods and limits for use,” §§4.2, 5.8.1, 6.3.4–6.3.5; printed pp. 10–11 and 21–23. Clause findings provided from the author’s standard copy; this paper’s specimen-continuity account relies on those supplied findings. The historical duration and sensor criteria are independently corroborated by PTB/BAM [34].
- [36] ABB / Lumacell. Industrial Catalogue, p. 8, comparison of hazardous-location gas-group designations: ethylene Group C / IIB. Used only to distinguish the broad electrical group from the manufacturer’s flame-arrester subgroup in [33]. <https://tnb.ca.abb.com/en/brands/lumacell/files/Industrial%20Catalogue%20-%20web.pdf> (checked September 16, 2026).

Standards currency note

Tables 1A–1B explicitly distinguish historical EN 12874:2001 propagation and burning criteria from EN ISO 16852:2010 and current approvals. The propagation counts follow PTB/BAM’s route-specific comparison; the earlier author chart remains a historical source. EN 12874:2001 was withdrawn and superseded. The current European/international framework is EN ISO/IEC 80079-49:2024 / ISO/IEC 80079-49:2024. Confirm current editions, regulatory incorporations and the exact product certificate before procurement. [3,5,34,35]

Appendix A. Optional Engineering Analysis of Critical Velocity and IOP

This appendix provides optional engineering analysis for a supported flashback-threshold assessment. It is not a prerequisite where a suitable device's certified limits already cover the application. The equations and examples distinguish local flow and pressure from mechanical ratings and do not confer product approval. The original Paradox pressure-duty distinction and the additional model limits are identified below. [6,10,11]

A.1 Separate the pressure requirements

Mechanical design pressure addresses the housing, flanges, bolting, gaskets, and other pressure-retaining parts, including normal service and credible upset loads. The flame-stopping pressure rating concerns the combustible mixture and the conditions covered by the actual approval and test program. Neither rating substitutes for the other. [2,6]

For this assessment, initial pressure P_0 is the absolute pressure of the unburned combustible mixture immediately before ignition or the initiating combustion event. It is not the subsequent explosion peak, and “initial” does not mean the lowest pressure during shutdown. Evaluate each potentially ignitable section and its connection to the arrester; a spatially nonuniform pressure field requires a suitable system model.

Certified operating limits remain binding

USCG Appendix A, §2.2, limits application to the maximum operating pressure specified in the manufacturer's certification. A higher mechanical rating does not authorize exceeding that limit. Any distinction between allowable flowing pressure and flame-stopping IOP must be expressly supported by the applicable certification, manufacturer instructions, and regulatory acceptance—not inferred from velocity alone. [2]

A.2 What “critical velocity” means

Critical or burn-back velocity is the limiting flow condition for the particular flashback mechanism being considered. Laminar burning velocity S_l is a mixture property under specified conditions; it is not automatically the critical average velocity in a pipe. Slow near-wall flow, heat transfer, turbulence, and flame/flow interaction can change flashback behavior. [10,11]

A bulk velocity above a tabulated S_l therefore does not prove that upstream flame entry is impossible. Conversely, loss of forward velocity does not necessarily depressurize a line. Internal ignition, propagation with the flow, reverse flow, or a stagnant branch may produce a challenge outside a simple upstream burn-back calculation. These possibilities belong in the scenario review.

A.3 A conditional formula for critical velocity

For the classical critical-gradient approach, assume a homogeneous premixed gas with a fully developed, constant-property, low-Mach-number laminar velocity profile in a circular tube. With bulk mean velocity U , radius $R = D/2$, and radial position r , the parabolic profile and its wall gradient give the following relationship. It converts an established critical gradient into a mean velocity; it does not independently establish the flashback limit. [10]

$$u(r) = 2U \left(1 - \frac{r^2}{R^2}\right); g = \frac{8U}{D} \quad (\text{A-1})$$

$$U_{crit} = \frac{D g_{crit}}{8} \quad (\text{A-2})$$

Here U_{crit} is in m/s when D is in metres and g_{crit} is in s^{-1} . The critical boundary velocity gradient g_{crit} must come from measurements or a validated model applicable to the mixture, pressure, temperature, wall condition, tube/burner geometry, and relevant flashback mode. It cannot be obtained from gas-group designation or MESG alone.

Use Equation (A-2) only inside the validated range of that model. Do not extend a laminar or unconfined-burner correlation to a turbulent, obstructed, heated, recirculating, or rapidly changing process header without supporting validation. Published burner research identifies heat-transfer and flame-structure effects omitted by the simplest critical-gradient treatment. [11]

Illustrative arithmetic—not gas-property or product-rating data

Assume $D = 0.006$ m, $g_{crit} = 500$ s^{-1} , and kinematic viscosity $\nu = 1.5 \times 10^{-5}$ m^2/s . These are hypothetical inputs, not recommended values for methanol, hydrogen, or any gas group.

Quantity	Calculation	Illustrative result
Critical mean velocity	$0.006 \times 500 / 8$	0.375 m/s
Pipe cross-sectional area	$\pi \times 0.006^2 / 4$	2.827×10^{-5} m^2
Actual flow at the threshold	$\text{Area} \times 0.375$	1.060×10^{-5} $m^3/s = 0.636$ L/min
Reynolds number, $Re = UD/\nu$	$0.375 \times 0.006 / (1.5 \times 10^{-5})$	150

The Reynolds-number check is consistent with the assumed laminar example; it does not validate the assumed g_{crit} , wall behavior, or flame model. A critical-velocity value suitable for an industrial installation requires its own evidence. Use the actual internal diameter, not nominal pipe size.

A.4 Convert the process flow to actual gas velocity

For a cross section with approximately uniform gas density, the bulk mean velocity follows from continuity. Use local actual volumetric flow Q_{act} , or mass flow $\dot{m}$ and local density ρ . [12]

$$U = \frac{Q_{act}}{A} = \frac{\dot{m}}{\rho A}; A = \frac{\pi D^2}{4} \quad (A-3)$$

Use A in m^2 , Q_{act} in m^3/s , $\dot{m}$ in kg/s , and ρ in kg/m^3 to obtain U in m/s . If density is nonuniform across the section, use the corresponding mass-flux calculation. During a transient, gas inventory can change, so the mass flow measured at one station need not equal the simultaneous flow at every other station.

For a single-phase gas, a chosen equation of state provides density. Writing a real-gas compressibility correction Z explicitly gives the following engineering extension of the ideal-gas relationship. R_s is the gas-mixture-specific gas constant, not the universal molar constant. [13]

$$\rho = \frac{P}{Z R_s T}; U = \frac{\dot{m} Z R_s T}{P A} \quad (A-4)$$

P is absolute pressure in Pa and T is absolute temperature in K when R_s is in $J/(kg \cdot K)$. Determine Z and mixture properties for the actual composition and state; use $Z = 1$ only where the ideal-gas approximation is justified.

For a flow reported at a reference or “standard” state, continuity and the equation of state give the following conversion, provided the composition and mass-flow basis are unchanged:

$$Q_{act} = Q_{ref} \frac{P_{ref}}{P} \frac{T}{T_{ref}} \frac{Z}{Z_{ref}} \quad (A-5)$$

Record the reference pressure and temperature. SCFM and actual CFM are not interchangeable. For example, with equal temperature and Z , a gas at twice its reference absolute pressure has half the actual volume flow for the same reference-basis flow. The final velocity must use the actual flow at the section being assessed.

Keep pipe velocity and element-cell velocity separate

A pipe flashback criterion uses the pipe cross-sectional area. An element-channel or burner-tip criterion requires its own validated velocity and area definition. Dividing by an arrester’s net open area does not establish a pipe critical velocity, and a pipe-velocity calculation does not establish an element’s flame-quenching rating.

A.5 Relate critical velocity to pressure

A velocity is not an absolute pressure. The term $\rho U^2/2$ is dynamic pressure, not the initial absolute pressure of a combustible mixture. A pressure prediction also needs boundary pressures, flow resistance, and the system's operating state. [15]

Restricted quasi-steady case

For a single, nearly constant-density, low-speed flow path, use a known downstream static pressure P_b . Between equal-area stations with comparable velocity profiles, negligible elevation change, no intervening pressure-adding machine, and fixed equipment positions, an engineering pressure-loss estimate at the flashback threshold is: [14]

$$P_{crit} \approx P_b + \left(f_D \frac{L}{D} + \Sigma K \right) \frac{\rho U_{crit}^2}{2} + \Delta P_{FA}(Q_{crit}) \quad (A-6)$$

$$Q_{crit} = A U_{crit} \quad (A-7)$$

f_D is the Darcy friction factor, L the pipe length, and ΣK the sum of applicable fitting-loss coefficients. ΔP_{FA} is the arrester pressure drop for the actual gas and flow. Include every resistance once; define the downstream boundary consistently. Area/profile changes or significant elevation differences need their corresponding energy terms. This simplified expression is not a compressible-network or rapid-blowdown model.

Evaluate density, friction factor, device pressure loss, and U_{crit} at the same state; iteration may be necessary. Do not assume constant friction factor through a change of flow regime or extrapolate an arrester pressure-drop curve outside its supported range. Where density changes are appreciable, use a compressible-flow calculation. [14]

Illustrative open-path calculation

Assume a separately validated $U_{crit} = 2.00$ m/s for a 0.100 m internal-diameter pipe. For arithmetic only, take $\rho = 1.20$ kg/m³, $(f_D L/D + \Sigma K) = 25$, $\Delta P_{FA} = 200$ Pa at the calculated flow, and $P_b = 101,325$ Pa absolute. The velocity is an assumed external input; it is not obtained by extending Equation (A-2) to this larger pipe.

$Q_{crit} = (\pi \times 0.100^2 / 4) \times 2.00 = 0.01571$ m³/s = 56.55 actual m³/h. The pipe/fitting loss is $25 \times 1.20 \times 2.00^2 / 2 = 60$ Pa. Thus $P_{crit} \approx 101,325 + 60 + 200 = 101,585$ Pa absolute = 1.01585 bar absolute.

This is the pressure for one assumed open-flow state—not a universal IOP and not authorization to select a 1.01585-bar-rated arrester. Changing backpressure, valve position, trapped inventory, or credible ignition location changes the required assessment. “Absolute” and “gauge” pressure must remain explicitly distinguished.

A.6 Shutdowns and trips require a pressure/flow history

When the steady-state assumptions do not apply, determine $U(t)$, $P(t)$, temperature, and composition together from an appropriately validated transient model or suitable operating evidence. For a specifically validated bulk flashback criterion, with P expressed as absolute pressure, the crossing condition is:

$$U(t_{crit}) = U_{crit}(t_{crit}); P_{crit} = P(t_{crit}) \quad (A-8)$$

The critical velocity may itself change with pressure, temperature, or composition. Check every relevant crossing and the states after it, not merely the first time the flow falls below a threshold. Rapid transients can invalidate a quasi-steady flashback criterion; that limitation must be assessed before applying Equation (A-8).

Develop scenarios for normal shutdown, emergency shutdown, blower/compressor trip, valve closure, loss of purge, reverse flow, trapped pressure, and connected-vessel pressure. A flowing line can become stagnant while still pressurized. Internal ignition and flame travel with the flow must be assessed separately from loss of upstream-flashback resistance.

Illustrative comparison: the same flow history, different pressure histories

The table below uses independently assumed event histories to show why velocity alone does not determine IOP. Assume $U_{crit} = 2.00$ m/s has already been validated over the relevant conditions. Neither pressure column is calculated from the velocity column, and neither describes a particular installation.

Time (s)	Bulk U (m/s)	Event A: rapid depressurization Pabs (bar)	Event B: pressure retained Pabs (bar)
0	10.00	4.46	4.46
5	5.00	2.20	4.30
10	2.00 (threshold)	1.15	4.00
15	0.50	1.05	3.95
20	0.00	1.013	3.95

At the assumed flashback threshold, Event A gives 1.15 bar absolute (about 16.7 psia), but Event B gives 4.00 bar absolute (about 58.0 psia). Both have the same mean velocity. If both are credible, the lower-pressure Event A cannot determine the required combustion-pressure coverage by itself.

A lower crossover estimate is conditional

A lower pressure at flashback onset can be relevant only when the complete hazard assessment supports it. It does not demonstrate that ignition at higher pressure is impossible, and it does not permit operation outside the product's certified pressure range. The example is a distinction between pressure duties, not a blanket permission to use a low-IOP product in a high-pressure line. [2,6]

A.7 Determine the minimum required rated IOP

The useful design quantity is the minimum required IOP rating, not the minimum pressure encountered in operation. Establish an upper envelope of the absolute pre-ignition pressures at which the arrester can credibly be challenged:

$$P_{IOP, req} = \max[P_{0,s}(x, t)] \quad (A-9)$$

Take the maximum over credible scenarios s , potentially ignitable locations x , and relevant times t , including normal, transient, low/zero/reverse-flow, and internal-ignition states. This is an engineering selection rule, not a standardized test equation.

$$P_{IOP, rated} \geq P_{IOP, req} \quad (A-10)$$

Include justified allowances for model, flame-limit, instrument, and operating uncertainty; no universal numerical safety factor is prescribed here. Verify gas group, temperature, propagation phenomena, direction, installation, and burn duty as well as pressure.

The permitted operating pressure in the certification and instructions remains binding. A lower calculated flashback-onset pressure does not authorize operation outside that range. [2]

When a critical-velocity calculation is necessary

A critical-velocity calculation is unnecessary when all credible pressure states are already covered by the selected arrester. It is needed when forward flow is credited with excluding a higher-pressure flashback condition; that credit requires system-specific evidence and acceptance under the governing approval basis.

If the flashback criterion or the pressure/flow history is not adequately established, do not take credit for an assumed reduction in IOP. Cover the highest credible pressure at which a combustible mixture can challenge the device, or redesign the process/protection arrangement and obtain the required acceptance.

Required engineering record

Retain the mixture basis; validated flashback data and limits; flow conversions; pressure/temperature/flow histories; piping and valve configurations; ignition locations; failed-protection assumptions; uncertainty allowances; and written manufacturer confirmation of product limits. Low-flow shutdown setpoints additionally require sensor/valve response-time and safety-system assessment: the onset threshold is not a safe trip setting by itself.

Appendix A source basis: [6] supplies the Paradox pressure-duty distinction. References [10,11] support flashback-model limitations; [12–15] support flow and pressure relationships. Equations (A-3)–(A-7) include stated engineering derivations. Numerical examples are hypothetical, and the scenario-envelope rule is an engineering selection method, not a quoted test-standard equation.